

(54) MANAGEMENT OF MULTIPLE MEMORY IN-FIELD SELF-REPAIR OPTIONS

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References Cited

U.S. PATENT DOCUMENTS

6,874,111

B1

3/2005

Adams et al.

8,495,436

B1 *

7/2013

Agrawal

.....

G11C 29/4401

714/710

2001/0052093

A1 *

12/2001

Oshima

.....

G11C 29/56

714/719

2004/0246796

A1 *

12/2004

Konuk

.....

G11C 29/44

365/200

2005/0047229

A1 *

3/2005

Nadeau-Dostie

.....

G11C 29/40

365/201

2005/0172180

A1 *

8/2005

Damodaran

.....

G11C 29/16

714/723

2009/0199056

A1 *

8/2009

Murata

.....

G11C 29/44

714/704

2013/0212207

A1 *

8/2013

Ong

.....

G06F 3/0601

709/213

2014/0245105

A1 *

8/2014

Chung

.....

G06F 11/1076

714/763

(Continued)

OTHER PUBLICATIONS

PCT International Search Report; PCT/US 2020/025999; dated Jun. 25, 2020; 2 pages.

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(57)

ABSTRACT

A system includes a processor and a memory set coupled to the processor. The system also includes a repair circuit coupled to the memory set. The repair circuit includes a first repair circuit and a second repair circuit. The repair circuit also includes a test controller configured to select between the first repair circuit and the second repair circuit to perform an in-field self-repair of the memory set.

18 Claims, 5 Drawing Sheets

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graph LR
    100[SYSTEM]
    102[PROCESSOR 102]
    110[MEMORY REPAIR CIRCUIT]
    130[MEMORY SET 130]
    
    102 <--> 110
    110 <--> 130
    
    subgraph 110 [MEMORY REPAIR CIRCUIT]
        112[TEST CIRCUIT]
        116[TEST CONTROLLER]
        118[FIRST REPAIR CIRCUIT]
        122[SECOND REPAIR CIRCUIT]
        124[REPAIR ANALYZER]
        124[SHADOW FUSE REGISTER]
    end
    
    subgraph 130 [MEMORY SET]
        132A[UNIT 1]
        132B[UNIT 2]
        132N[UNIT N]
    end
  
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(56) **References Cited**

U.S. PATENT DOCUMENTS

2015/0270016 A1 9/2015 Varadarajan et al.
2016/0155515 A1 6/2016 Son et al.
2017/0147434 A1* 5/2017 Bae G06F 11/1048
2017/0184662 A1* 6/2017 Varadarajan G11C 29/70
2017/0308447 A1* 10/2017 Wu G11C 29/835
2017/0372791 A1 12/2017 Hatsuda
2018/0314595 A1 11/2018 Eichmeyer et al.
2019/0087263 A1* 3/2019 Cha G06F 11/1072
2019/0107576 A1* 4/2019 Sinegre G01R 31/31719
2019/0140666 A1* 5/2019 Lee G06F 11/1068
2019/0250985 A1* 8/2019 Seo G06F 11/1068

* cited by examiner

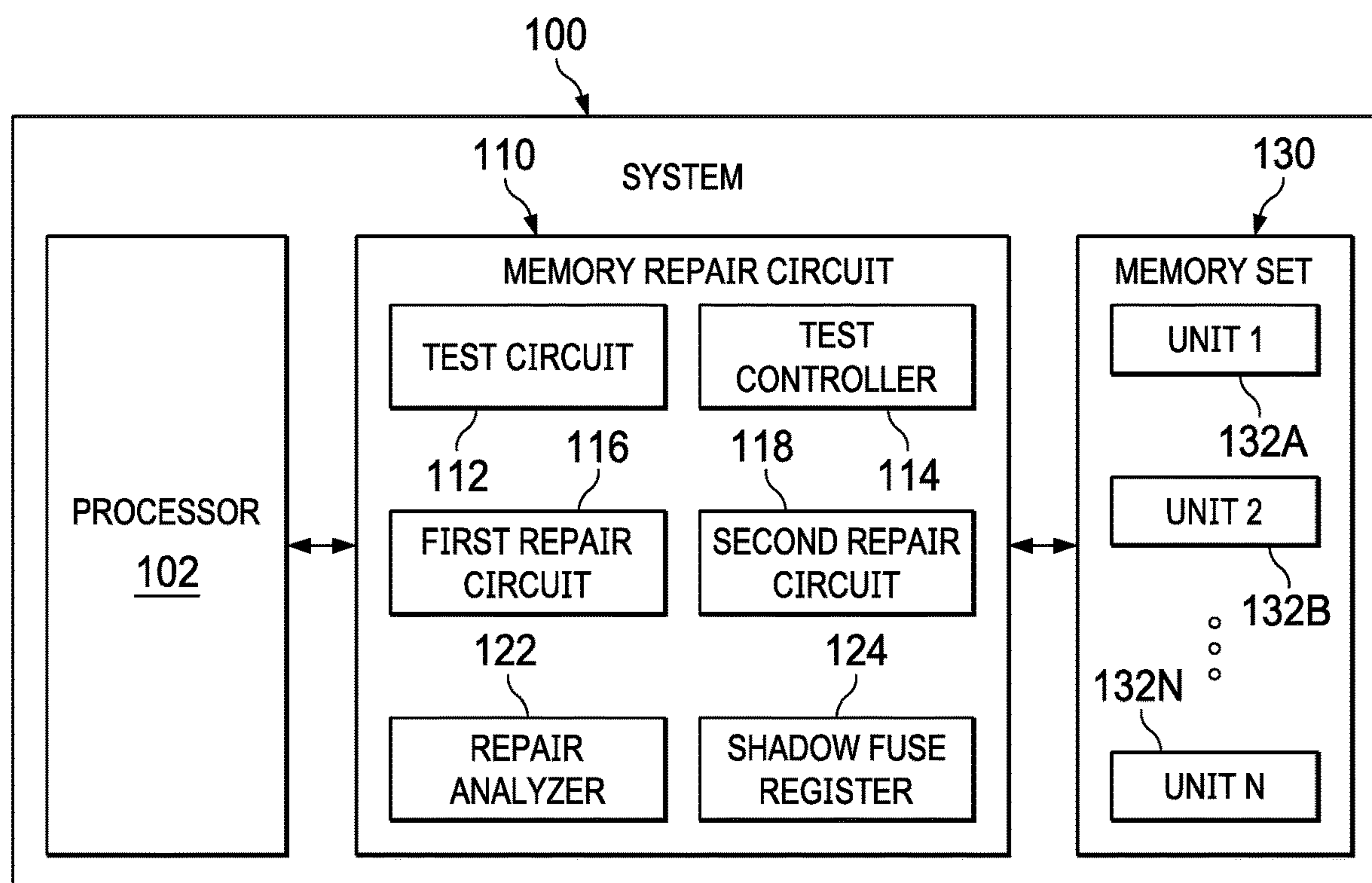


FIG. 1

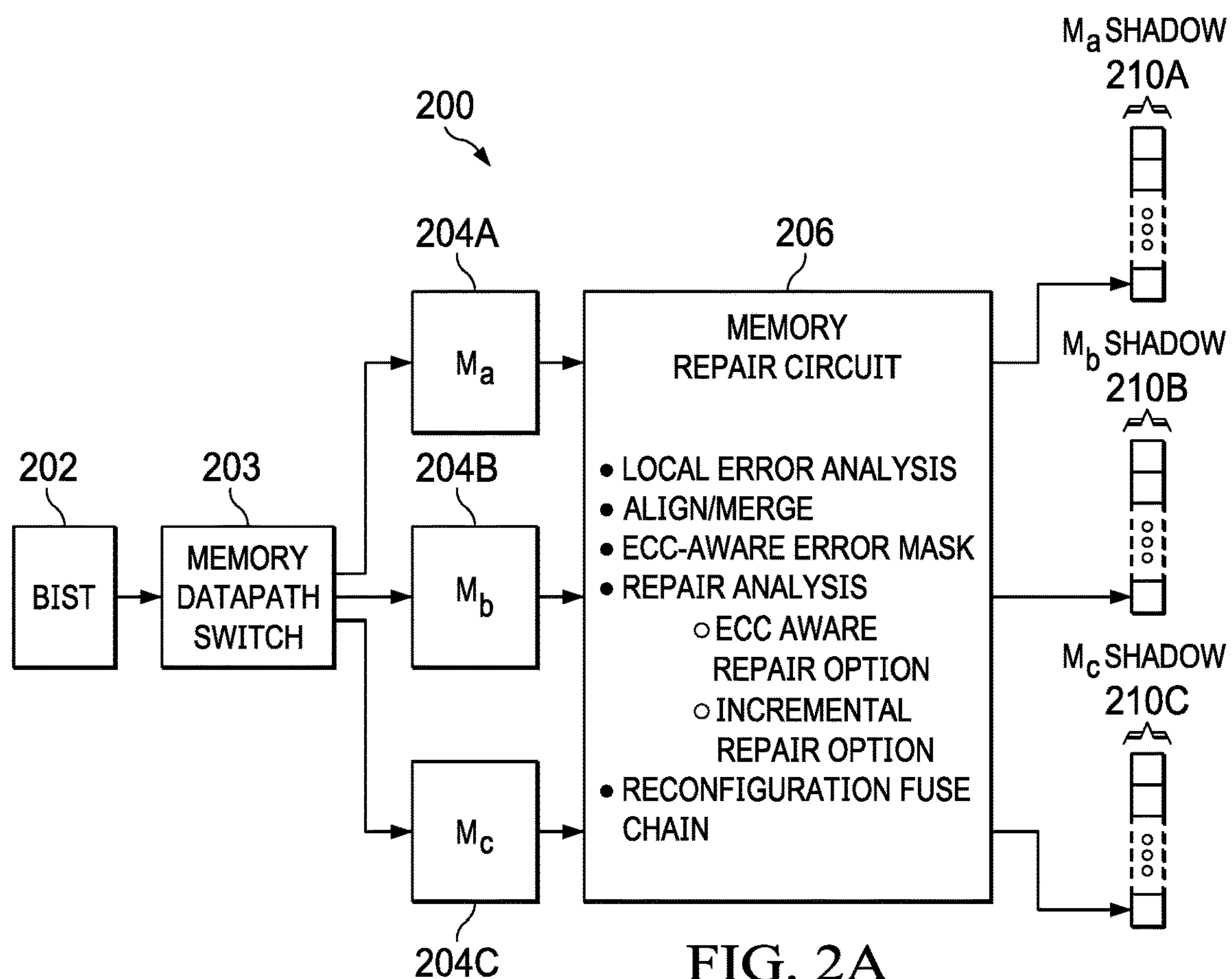
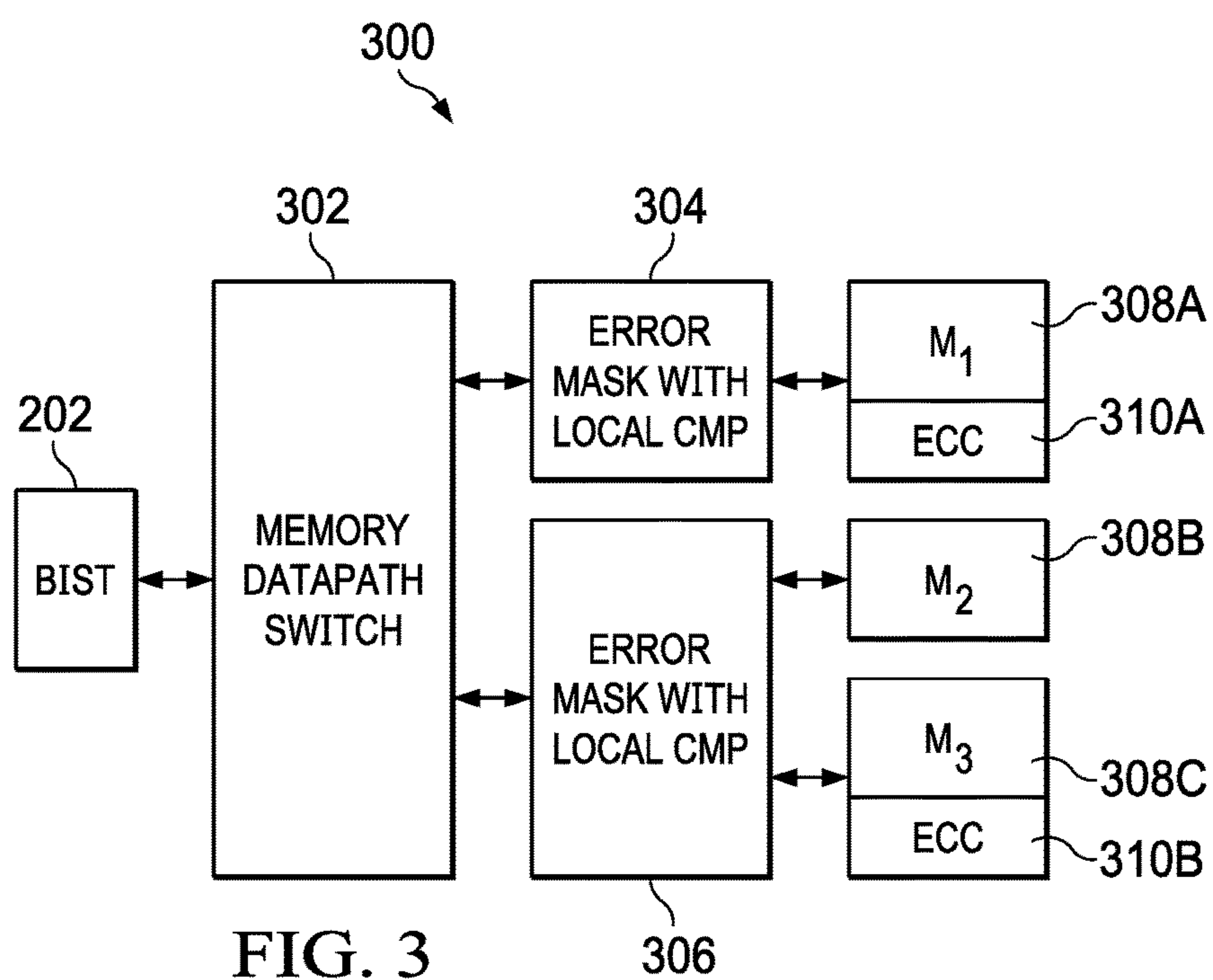
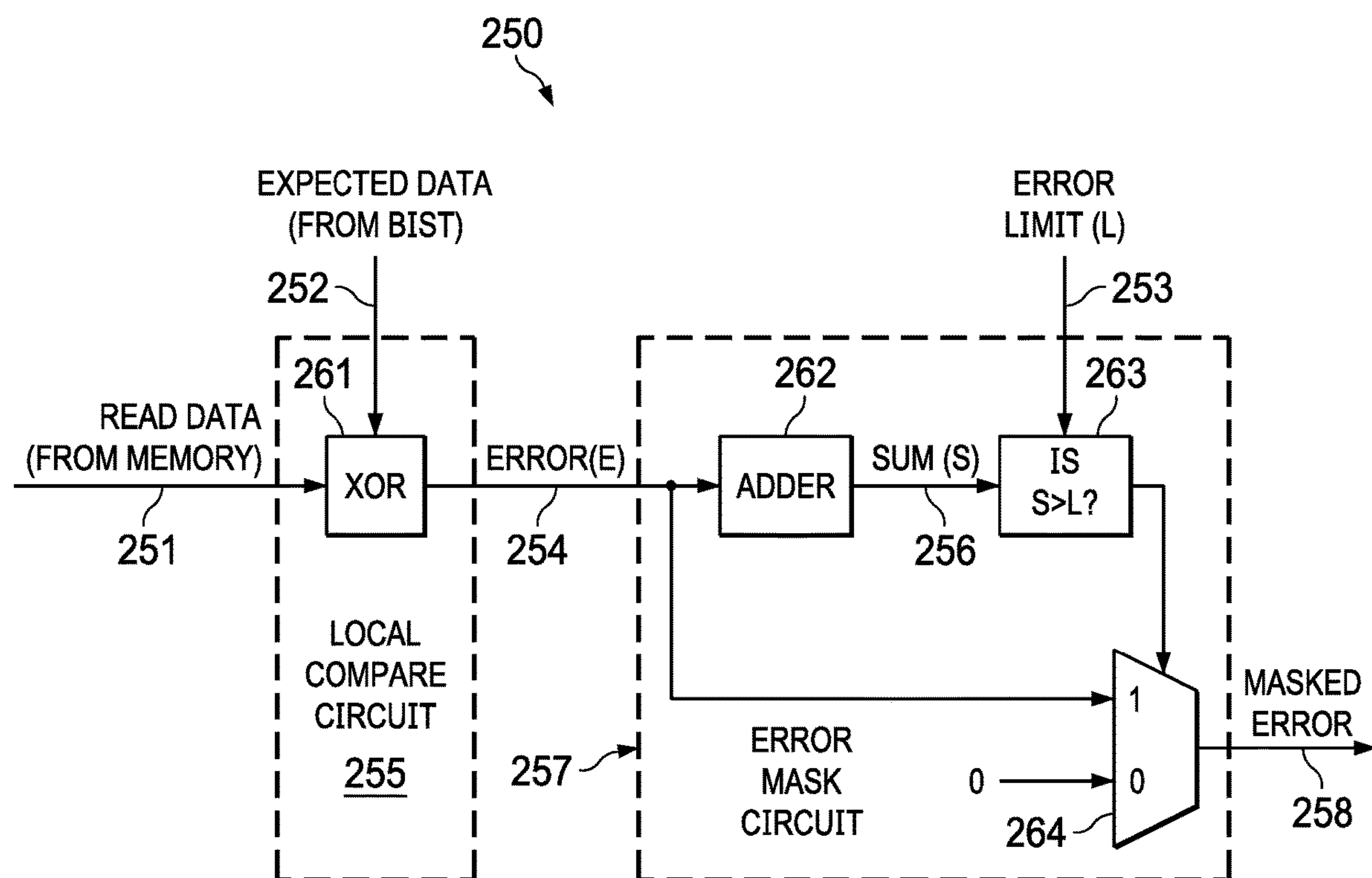


FIG. 2A



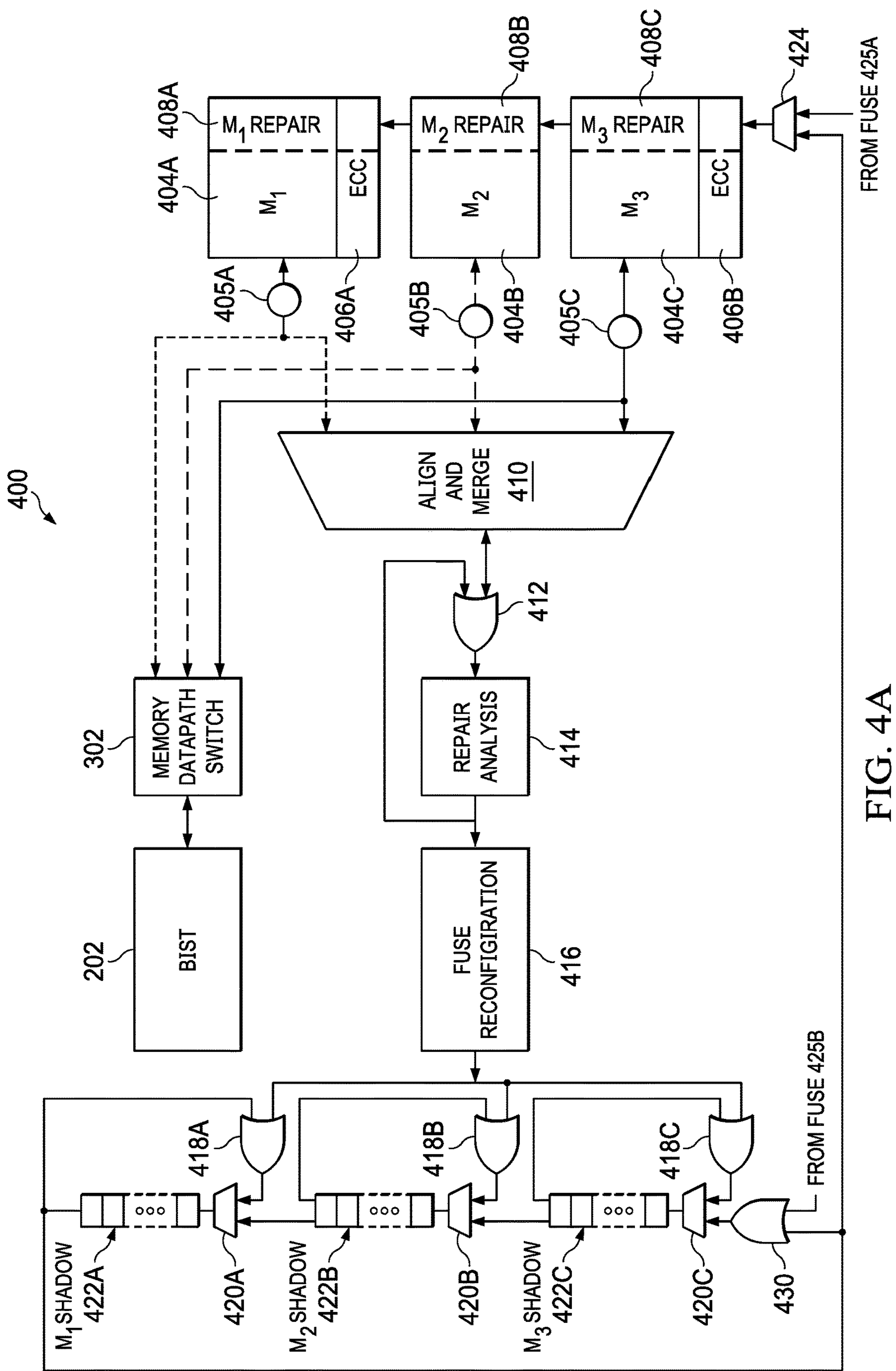


FIG. 4A

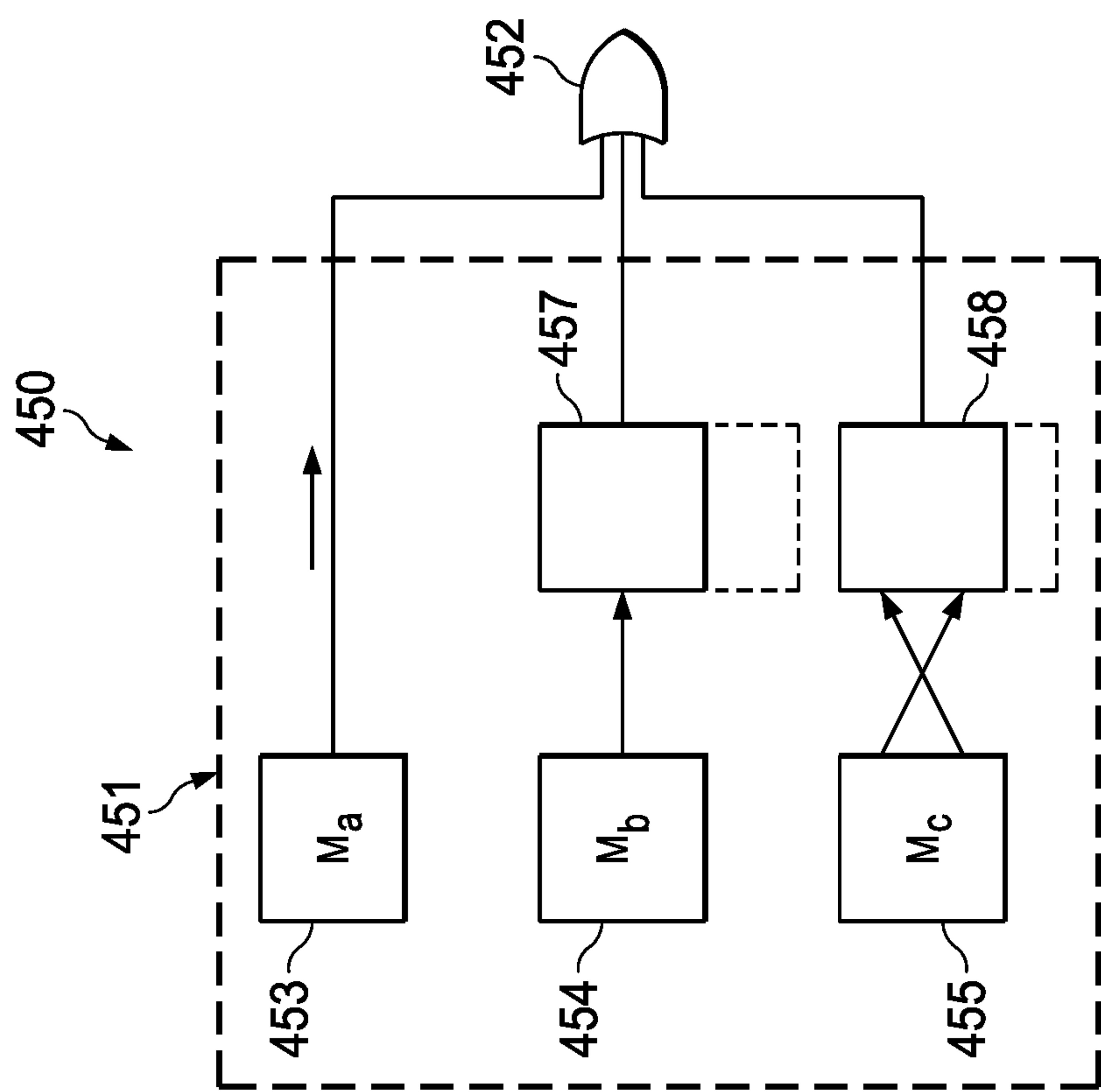


FIG. 4B

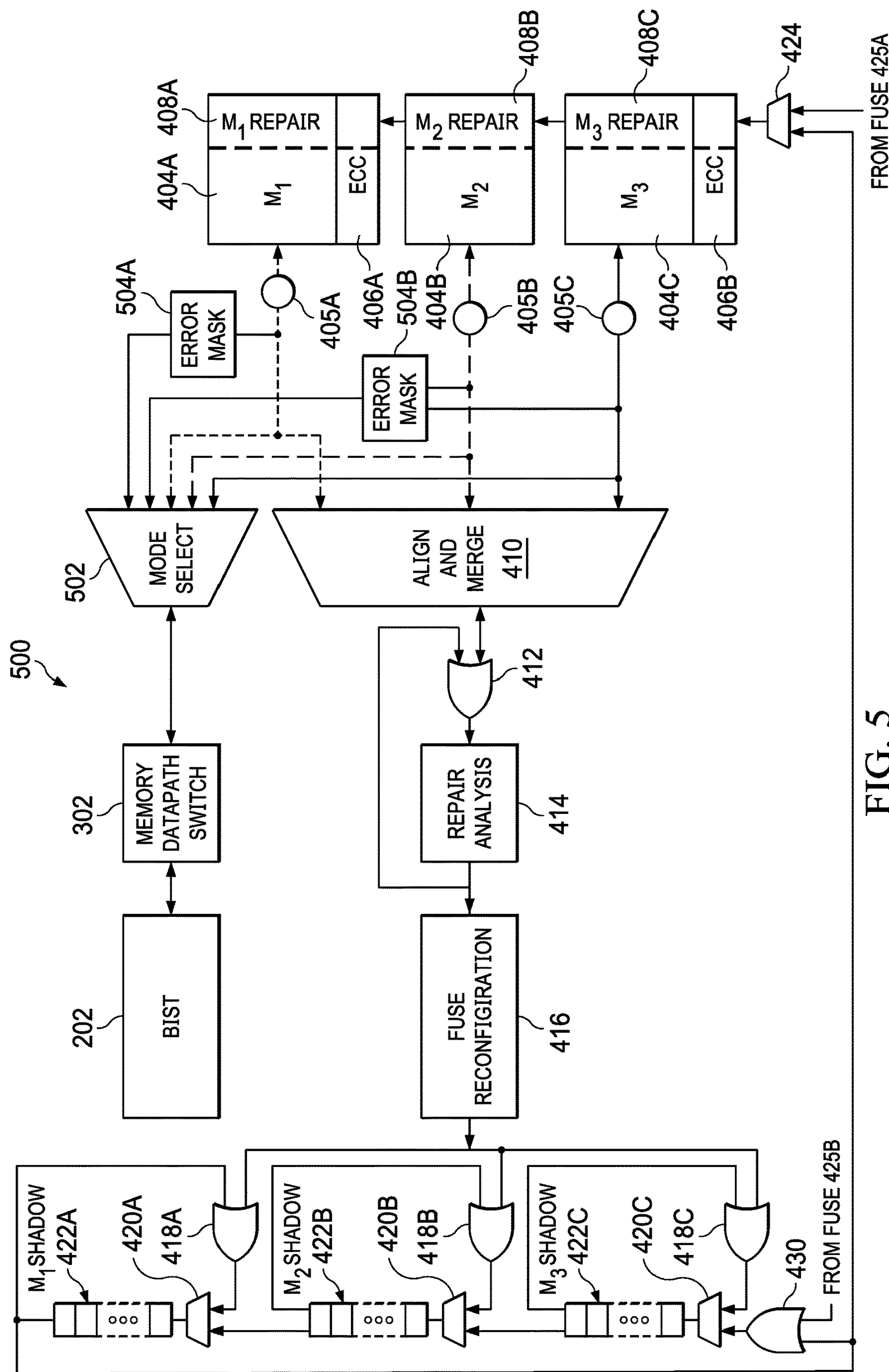


FIG. 5

MANAGEMENT OF MULTIPLE MEMORY IN-FIELD SELF-REPAIR OPTIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to U.S. Provisional Patent Application No. 62/828,543, filed Apr. 3, 2019, titled "Management of Multiple Memory In-Field Self-Repair Options," which is hereby incorporated herein by reference in its entirety.

BACKGROUND

Integrated circuits (ICs) generally include various modules combined to perform various functions. For example, a digital signal processor (DSP) includes processor and memory blocks embedded in the IC. The memory blocks containing plurality of addressable memory locations are tested for defects, ensuring the operability of the IC. To test these blocks, special test circuits, referred to as "Built-In Self Test" (BIST) circuits are incorporated into the IC. BIST circuits generate a test pattern to determine whether the memory block is defective or not. In some cases, the circuit provides redundant rows and/or columns that are used to reconfigure the memory to use redundant rows and/or columns instead of the defective rows and/or columns in the memory block. The process of reconfiguring the memory to use redundant rows and/or columns instead of defective rows and/or columns is referred to as physical memory repair.

Electronic fuse (e.g., Efuse or fuseROM) components are also used for memory repair. Electronic fuse components store repair data or repair signatures to identify and repair defective elements of memory blocks. The number of electronic fuse components is directly related to the sum of the number of memory blocks under test. With increasing memory blocks in modern system-on-a-chip (SoC) products, memory repair has become crucial to improve yield during manufacturing test and the use of error-correcting codes (ECC) to tolerate errors has become prevalent to improve reliability of these memory blocks in the field during functional operation. Known implementations of ECC involve storing an additional signature along with the memory data wherein the signature satisfies a specific mathematical equation with the data. Upon every memory read, both data and signature are read and the mathematical equation of read data is evaluated. The evaluated signature is compared with the stored signature that is read to detect and correct errors in the data. The number of signature bits and/or the mathematical equation used determines the number of errors that can be detected and/or corrected. The process of correcting the errors in the memory with ECC is referred to as logical memory repair. Efforts to balance IC footprint size, memory test and repair efficiency, and memory repair flexibility are ongoing.

SUMMARY

In accordance with at least one example of the disclosure, a system comprises a processor and a memory set coupled to the processor. The system also comprises a memory repair circuit coupled to the memory set. The memory repair circuit comprises a first repair circuit and a second repair circuit. The memory repair circuit also comprises a test controller

configured to select between the first repair circuit and the second repair circuit to perform an in-field self-repair of the memory set.

In accordance with at least one example of the disclosure, a device comprises a memory set and a memory repair circuit coupled to the memory set. The memory repair circuit comprises a test circuit, an error mask circuit, and an incremental repair circuit. The memory repair circuit also comprises a test controller coupled to the test circuit, the error mask circuit, and the incremental repair circuit. The test controller is configured to select between the error mask circuit and the incremental repair circuit to perform an in-field self-repair of the memory set.

In accordance with at least one example of the disclosure, a system-on-a-chip (SoC) comprises a memory set with a plurality of different memory units, each of the different memory units having its own repair architecture. The SoC also comprises a memory repair circuit coupled to the memory set. The memory repair circuit comprises a test circuit configured to: provide a local pass/fail determination for each of the different memory units within the memory set, provide error-correcting code (ECC)-aware regionalization of a dataword, and provide ECC-aware error masking. The memory repair circuit also comprises a repair circuit configured to repair in-field self-repair of the memory set. The memory repair circuit also comprises a test controller coupled to the test circuit and the repair circuit, wherein the test controller is configured to selectively enable and disable the repair circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of various examples, reference will now be made to the accompanying drawings in which:

FIG. 1 is a block diagram showing a system in accordance with some examples;

FIG. 2A is a block diagram showing a memory repair scenario in accordance with some examples;

FIG. 2B is a block diagram showing an error mask circuit used in memory repair in accordance with some examples;

FIG. 3 is a block diagram showing a memory repair scenario in accordance with some examples;

FIG. 4A is a schematic diagram showing a memory repair scenario in accordance with some examples;

FIG. 4B is a schematic diagram showing an align and merge circuit related to the memory repair scenario of FIG. 4A in accordance with some examples; and

FIG. 5 is a schematic diagram showing a memory repair scenario related to the memory repair scenario in accordance with some examples.

DETAILED DESCRIPTION

Disclosed herein are systems with multiple memory in-field self-repair options and related control components and methods. An example system is a system-on-a-chip (SoC) integrated circuit (IC), where the system includes a processor and a memory set coupled to the processor. The system also includes a memory repair circuit coupled to the memory set. In some examples, the memory repair circuit comprises a first repair circuit and a second repair circuit. The memory repair circuit also comprises a test controller configured to select between the first repair circuit and the second repair circuit to perform an in-field self-repair of the memory set. In other examples, the memory repair circuit comprises at least one repair circuit that is selectively enabled or disabled by a test controller. In some examples, the repair circuit or

first repair circuit is an error mask circuit. Meanwhile, the second repair circuit is an incremental repair circuit. As used herein, an “error mask circuit” refers to a circuit that is programmed to mask a predefined number of bit errors in the memory output data. As used herein, an “incremental repair circuit” refers to a circuit that is capable of incrementally reconfiguring the memory in the field to use additional redundant rows and/or columns to replace defective rows and/or columns. The term incremental is used to indicate that this repair or reconfiguration done in-field should be in addition to those already repaired during manufacturing test. In some examples, the memory set includes a plurality of different memory units, each of the different memory units having its own repair architecture. As needed, the memory repair circuit is configured to adjust itself based on the respective repair architectures for each of the different memory units.

In some examples, a repair circuit is enabled or disabled based on in-field debug and/or diagnostic operations. In some examples, in response to a repair need and/or based upon a predetermined repair strategy, the test controller is configured to select between the first repair circuit and the second repair circuit to perform an in-field self-repair of the memory set or individual memory units of the memory set. In one example, the test controller selects the first repair circuit to perform an in-field self-repair on one of the different memory units in response to the test controller determining that a repair compatible with the first repair circuit is available. In another example, the test controller selects the second repair circuit to perform in-field self-repair on one of the different memory units in response to the test controller determining that a repair compatible with the first repair circuit is not available.

In some examples, the memory repair circuit includes components configured to provide: 1) a local pass/fail or error determination for each of the different memory units of a memory set; 2) ECC-aware regionalization of a dataword; and 3) ECC-aware error masking. In some examples, the memory repair circuit also includes a shadow fuse register for each of the different memory units, where each shadow fuse register is configured to be initialized with the respective repair code of the different memory units from a FuseROM upon every electronic fuse autoloading. The memory repair circuit is configured to provide a cumulative repair code for different memory test sessions, and to assert an error in response to identifying a non-repairable error based on the cumulative repair code. The memory repair circuit is also configured to selectively reload contents of a shadow fuse register into a respective one of the different memory units to perform in-field self-repair operations. To provide a better understanding, various memory repair circuit options involving management of multiple memory in-field self-repair options are described using the figures as follows.

FIG. 1 is a block diagram showing a system 100 in accordance with some examples. As shown, the system 100 includes a processor 102, a memory repair circuit 110 coupled to the processor 102, and a memory set 130 coupled to the memory repair circuit 110. In different examples, the system 100 is representative of an IC, SoC, or multi-die module.

In the example of FIG. 1, the memory set 130 includes a plurality of memory units 132A-132N, which correspond to different memory modules or different memory zones, where each of the memory unit 132A-132N has a different repair architecture. As used herein, a “repair architecture” may refer to physical repair architecture or logical repair architecture. A physical repair architecture involves recon-

figuring the memory unit to use a limited number of redundant rows and/or columns as needed to overcome the defective rows and/or columns of the respective memory unit. In contrast, a logical repair architecture refers to correcting the memory output using ECC. For example, a memory unit with an ECC repair architecture uses additional bits for storing signature that is used to automatically detect and correct errors. Meanwhile, a memory unit with an incremental repair architecture uses redundant rows and/or columns for repairs. Also, some memory units of a memory set may have both ECC repair architecture and incremental repair architecture, while other memory units of a memory set have only one repair architecture, or no repair architecture.

In the example of FIG. 1, memory repairs for the system 100 are performed by the memory repair circuit 110, which includes a test circuit 112, a test controller 114, a first repair circuit 116, and a second repair circuit 118. In some examples, the first repair circuit 116 corresponds to an ECC repair circuit, and the second repair circuit 118 corresponds to an incremental repair circuit. When a repair need is detected by the test circuit 112, the test controller 114 is configured to determine if the repair is possible for a given memory unit (the amount of redundant rows/columns available for each of the memory units 132A-132N is limited). To make this determination, the test controller 114 receives information from a repair analyzer circuit 122 and shadow fuse register(s) 124.

In response to a repair need and/or based upon a predetermined repair strategy, the test controller 114 is configured to select between the first repair circuit 116 and the second repair circuit 116 to perform an in-field self-repair of the memory set 130 or individual memory units 132A-132N of the memory set 130. In one example, the test controller 114 selects the first repair circuit 116 to perform an in-field self-repair on one of the different memory units 132A-132N in response to the test controller 114 determining that a repair compatible with the first repair circuit 116 is available. In another example, the test controller 114 selects the second repair circuit 118 to perform in-field self-repair on one of the different memory units 132A-132N in response to the test controller 114 determining that a repair compatible with the first repair circuit 116 is not available. In some examples, the first repair circuit 116 and/or the second repair circuit 118 is selectively enabled or disabled. Also, in some examples, one of the first repair circuit 116 and the second repair circuit 118 is omitted, and the remaining repair circuit is selectively enabled or disabled.

In one example, the system 100 includes only an ECC repair circuit, and the ECC repair circuit is selectively enabled and disabled. In another example, the system 100 includes only an incremental repair circuit, and the incremental repair circuit is selectively enabled and disabled. In another example, the system 100 includes both an ECC repair circuit and an incremental repair circuit, where the ECC repair circuit is selectively enabled and disabled. In another example, the system 100 includes both an ECC repair circuit and an incremental repair circuit, where the incremental repair circuit is selectively enabled and disabled. In another example, the system 100 includes both an ECC repair circuit and an incremental repair circuit, where both repair circuits are enabled or disabled. When both ECC and incremental repair circuits are enabled, one may have a higher priority when a repair is needed. In some examples, the priority level is predetermined (e.g., ECC repair or

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incremental repair preferred). In other examples, the priority level is adjustable based on user input or predetermined triggers.

In some examples, the test circuit **112** of the memory repair circuit **110** is configured to provide: 1) a local pass/fail or error determination for each of the different memory units **132A-132N** of a memory set **130**; 2) ECC-aware regionalization of a dataword; and 3) ECC-aware error masking. In some examples, the memory repair circuit **110** also includes a shadow fuse register **124** for each of the different memory units **132A-132N**, where each shadow fuse register **124** is configured to be initialized with the respective repair code of the different memory units from a FuseROM upon every electronic fuse autoload. The memory repair circuit **110** also comprises a repair analyzer circuit **122** configured to provide a cumulative repair code for different memory test sessions, and to assert an error in response to identifying a non-repairable error based on the cumulative repair code. As needed, the memory repair circuit **110** is configured to selectively reload contents of a shadow fuse register **124** into a respective one of the different memory units **132A-132N** to perform in-field self-repair operations.

FIG. 2A is a block diagram showing a memory repair scenario **200** in accordance with some examples. In the memory repair scenario **200**, various components are represented including a built-in self-test (BIST) unit **202** (an example of test circuit **112**), memory datapath switch **203**, memory units **204A-204C** (examples of the memory units **132A-132N** in FIG. 1), a memory repair analyzer circuit **206** (an example of at least some of the memory repair analyzer **122** in FIG. 1), and shadow fuse registers **210A-210C** (examples of the shadow fuse registers **124**). In different examples, the components represented for the memory repair scenario **200** are part of an IC, SoC, or multi-die module.

In the memory repair scenario **200**, the BIST unit **202** performs various operations (such as write and read) to test the memory units **204A-204C** before and after a repair is complete. For example, the BIST unit **202** may test the memory units with one or more test sequences using memory datapath switch **203**. The datapath switch **203** is used to select one or more of memory units **204A-204C** (simultaneous or not) for testing by the BIST unit **202** in a test session. The test sequences used by the BIST unit **202** may vary based on the order of operations on the memory (such as write and read), the data background that is used for the operations (e.g., all 0s, alternating 0-1s, etc.), addressing order of the words within the memory unit (e.g., increasing columns, decreasing rows, ping-pong, etc.), or other options. In some examples, multiple sequences are used for testing with each test sequence fine-tuned to target a specific defect within a memory unit.

To perform a repair, the memory repair circuit **206** is configured to perform various operations. In some examples, the memory repair circuit **206** includes local error analysis that compares the output of memory units with the expected value to identify errors local to each memory unit. In some examples, the memory repair circuit **206** includes align and merge components, which aligns and merges error values from diverse memory architectures into a unified memory architecture to reuse common circuitry for the subsequent stages of repair analyzer logic across diverse memory architecture. In some examples, the memory repair circuit **206** includes ECC-aware error mask components. The ECC-aware error mask components enable ECC-aware tests and repair options. As desired, the memory repair circuit **206**

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may be configured to bypass the ECC-aware error mask components. In such case, ECC-aware tests and repair options are not available.

As represented in FIG. 2A, the memory repair circuit **206** also includes repair analysis components. In some examples, the repair analysis components support an ECC option and an incremental repair option. For the ECC repair option, the repair analysis components work with the ECC-aware error mask components. Thus, if the ECC-aware error mask components are bypassed, the ECC repair option is not available. Also, in different examples, the ECC repair option and the incremental repair option have different priorities. In one example, the ECC repair option has a higher priority than the incremental repair option. In another example, the ECC repair option has a lower priority than the incremental repair option.

ECC repair and/or incremental repair may be enabled or disabled for in-field debug and diagnostic reasons. In some scenarios, the ECC repair option is the only memory repair option available. In such scenarios, ECC repairs are selectively enabled or disabled. In some scenarios, only an incremental repair option is available. In such scenarios, the incremental repair option is selectively enabled or disabled. In some scenarios, both an ECC option and an incremental repair option is available. In such scenarios, one of the available repair options is given higher priority. In some examples, incremental repair requires reprogramming FuseROMs to store the additional repair values resulting in additional latency for memory test. In other examples, ECC repair requires calculating signature and correcting the data in case of signature mismatch resulting in additional latency for memory test. For latency-sensitive applications, ECC repair or incremental repair may be given a higher priority based on its relative latency overhead.

In some examples where align and merge components are used, the memory repair circuit **206** also includes reconfigurable fuse chain components that helps reconfigure the fuse encode information from the unified memory repair architecture (resulting from align/merge and repair analysis operations) back to the repair architecture of the specific memory unit under test. The reconfiguration fuse chain component of the memory repair circuit **206** receives the fuse encode information from the repair analysis component of the memory repair circuit **206** and updates the shadow fuse registers **210A-210C**, where the shadow fuse register **210A** stores repair information (e.g., a repair signature that tracks all repairs) for the memory unit **204A**, the shadow fuse register **210B** stores repair information for the memory unit **204B**, and the shadow fuse register **210C** stores repair information for the memory unit **204C**.

FIG. 2B is a block diagram showing an error mask circuit **250** used in memory repair in accordance with some examples. In the example of FIG. 2B, the error mask circuit **250** (an example of the ECC-aware error mask in **206** in FIG. 2) is able to mask a predefined number of errors. The error mask circuit **250** has as its inputs the output data from memory **251**, expected data **252** and a predefined error limit **253** (labeled "L") as per the supported ECC configuration of the respective memory. The error mask circuit **250** first computes the error **254** (labeled "E") between the output data and the expected data, which may be achieved using an exclusive-OR operation **261**. In the example of FIG. 2B, the error mask circuit **250** includes local compare logic **255**, which compares the memory output with the expected data local to each memory unit. The error mask circuit **250** then computes the total number of bit errors **256** (labeled "S"), which may be achieved using an addition operation **262**. The

value **256** is checked to be greater than the error limit **253** in the logic **263**. If the comparison of logic **263** is false (indicating the number of errors being less than the limit **L**), the multiplexer **264** returns 0 as the output masked error **258**. Otherwise, the error mask circuit returns the computed error **254** as the output masked error **258**.

FIG. 3 is a block diagram showing a memory repair scenario **300** in accordance with some examples. In the memory repair scenario **300**, various components are represented including the BIST unit **202**, a memory datapath switch **302**, a first ECC-aware error mask component **304**, a second ECC-aware error mask component **306**, and memory units **308A-308C**. In the example of FIG. 3, the memory datapath switch **302** performs the same function as the memory datapath switch **203** of FIG. 2 and enables the BIST unit **202** to test one or more memory units **308A-308C** simultaneously in a test session. The first and second ECC-aware error mask components **304** and **306** perform the same function as the error mask component **250** of FIG. 2B. In different examples, the components represented for the memory repair scenario **300** are part of an IC, SoC, or multi-die module.

In the memory repair scenario **300**, the BIST unit **202** performs various operations to test the memory units **308A-308C** before and after a repair is complete. In the memory repair scenario **300**, the memory units **308A** and **308C** support ECC repairs. More specifically, the memory unit **308A** includes additional bits **310A** to store ECC signature for ECC repairs. The memory unit **308C** also includes additional bits **310B** to store ECC signature to support ECC repairs on memory units **308B** and **308C**. Note: the number of additional bits **310B** may have the same number or a different number relative to the number of additional bits **310A**. Also, the memory unit **308B** does not include signature bits within it and instead relies on signature bits stored within **308C**. Thus, each of the memory units **308A-308C** includes its own repair architecture (or no repair architecture) in the memory repair scenario **300**.

The error mask with local compare components **304** and **306** enable ECC-aware tests and repair options and are example implementations of error mask with local compare circuit **250** of FIG. 2B. As desired, the error mask components **304** and **306** may be bypassed. In such case, ECC-aware tests and repair options are not available. Thus, when the first and second error mask components **304** and **306** are enabled, ECC repairs for the memory units **308A**, **308B** and **308C** are available (with **308B** and **308C** sharing the signature **310B** and having a common shared bit error limit **L** as illustrated in **253** of FIG. 2a). On the other hand, when the first and second error mask components **304** and **306** are disabled, ECC repairs for the memory units **308A**, **308B** and **308C** are not available even if there are bit errors that can be corrected with **310A** and **310B**.

In the memory repair scenario **400** of FIG. 4A, various components are represented including the BIST unit **202**, the memory datapath switch **302**, memory units **404A-404C**, local comparator units **405A-405C**, an align and merge circuit **410**, an OR gate **412**, a repair analysis circuit **414**, and a fuse reconfiguration circuit **416**. The memory repair scenario **400** also includes shadow fuse registers **422A-422C**, OR gates **418A-418C** and **430**, and multiplexers **420A-420C** and **424**. During the system power-up or initialization sequence before any functional or test operations on the memory units, shadow fuse registers **422A-422C** are reset/cleared and the memory repair data (possibly from prior test sessions) stored in FuseROM or a similar non-volatile memory is serially loaded into the corresponding memory

repair registers **408A-408C** through the input **425A** and multiplexer **424**. Simultaneously, the corresponding shadow fuse registers **422A-422C** are also serially initialized with the same memory repair data through the input **425B** and multiplexers **420A-420C**. Thus, at the end of system initialization, the shadow fuse registers **422A-422C** has identical data as the corresponding memory repair register **408A-408C**. In the example of FIG. 4, a test controller circuit (e.g., the test controller **114** of FIG. 1) controls the multiplexers **424**, **420A-C** and enables incremental repair components **410**, **414**, **416**, **422A-422C**. In different examples, the components represented for the memory repair scenario **400** are part of an IC, SoC, or multi-die module.

In the memory repair scenario **400**, the BIST unit **202** performs various operations to test the memory units **404A-404C** before and after a repair is complete. In the memory repair scenario **400**, the memory units **404A** and **404C** support ECC repairs and incremental repairs. Meanwhile, the memory unit **404B** supports incremental repairs only while relying on memory unit **404C** for ECC repair. More specifically, the memory unit **404A** includes: 1) additional storage **406A** to store signature for ECC repairs; and 2) a set of redundant row/column elements **408A** to support incremental repairs. Also, the memory unit **404B** includes a set of redundant row/column elements **408B** to support incremental repairs. Also, the memory unit **404C** includes: 1) additional storage **406B** to store signature for ECC repairs; and 2) a set of redundant row/column elements **408A** to support incremental repairs. Note: each of the sets of ECC signature storage elements **406A** and **406B** may have the same number or a different number of bits. Also, each of the sets of redundant row/column elements **408A-408C** may have the same number or a different number of redundant elements. Thus, each of the memory units **404A-404C** includes its own repair architecture in the memory repair scenario **400**.

To perform memory repairs in the memory repair scenario **400**, the BIST unit **202** tests the memory units **404A-404C** to determine if memory repair is needed. In response to the test from BIST unit, the local compare circuits **405A-405C** compute the error from the respective memory units **404A-404C**. The local compare circuits **405A-405C** are instances of the local compare circuit **255** of FIG. 2B to compute the error from the memory units **404A-404C**. The errors from diverse memory units are aligned to a unified format and merged together by the align and merge circuit **410**. The cumulative repair information from the align and merge circuit **410** is provided to a repair analysis circuit **414** via an OR gate **412**. The output of the repair analysis circuit **414** is provided back to the OR gate **412**. The feedback to the OR gate enables incrementally cumulating repairs where errors from multiple test sequences run back-to-back on the same memory unit are cumulated.

The output of the repair analysis circuit **414** is also provided to a fuse reconfiguration circuit **416**, which performs the inverse operation of align and merge circuit **410** to reconfigure the repair analysis output in the unified format (converted by align and merge circuit **410**) back to the target memory repair architecture. The fuse reconfiguration circuit **416** then writes cumulative repair information (a repair signature for each of the memory units **404A-404C**) to shadow fuse registers **422A-422C**. The OR gates **418A-418C** merges the previously stored repair signature from the shadow fuse register (either from the power-up initialization or prior test sessions) with the new repair signature from the fuse reconfiguration unit **416** and the multiplexers **420A-420C** configures the shadow fuse registers to store back the new merged repair signature.

As shown, the outputs from each of the shadow fuse registers **422A-422C** is fed back to a respective OR gate **418A-418C** and respective multiplexer **420A-420C**. After the BIST unit **202** completes testing on all memory units **404A-404C**, the newly identified memory repair signature from the shadow fuse registers **422A-422C** is stored into the memory repair registers **408A-408C** by shifting out through the other input of the multiplexer **424**. The other input to the multiplexers **420A-420C** are configured to form a shift register by passing the repair information from adjacent shadow fuse registers for each of the memory units **404A-404C**. As shown, the output from the shadow fuse register **422A** (corresponding to the memory unit **404A**) is fed into a multiplexer **424**, where the output of the multiplexer **424** is provided to the memory unit **404C**. While the data from shadow fuse register **422A** is shifted into memory repair register **408C**, the data stored in the shadow fuse registers **420C** and **420B** would have also been shifted into **420B** and **420A**, respectively. This process continues till the repair registers **408A**, **408B** and **408C** are initialized with the data from the shadow fuse registers **422A**, **422B** and **422C** respectively. The OR-gate **430** ensures that the shadow fuse registers **422A-422C** re-circulates its data back during this process. This enables full incremental repair where previous memory repair data stored in **408A-408C** which was identical to those stored in the shadow registers **422A-422C** (either from initial load from FuseROM or from previous BIST executions), is cumulated with the fails from the new BIST test session and repaired back into the respective memory units. At any point in the process (e.g., at local compare or at align and merge or at repair analysis or at fuse reconfiguration or at shadow fuse accumulation), if a non-repairable error or a failure is identified, the BIST system asserts an error indicating a non-repairable failure.

FIG. 4B is a schematic diagram showing an align and merge circuit **450** (an example of the align and merge circuit **410** in FIG. 4A) related to the memory repair scenario of FIG. 4A in accordance with some examples. In the example of FIG. 4B, the align and merge circuit **450** includes a component **451** configured to perform the align function. The align and merge circuit **450** also includes an OR gate **452** to perform the merge function. As shown, the component **451** includes memory units **453-455**. The memory unit **453** (labeled "Ma") has a unified format so that no transformation is performed. The memory unit **454** is shorter than the memory **453** and is aligned to the unified format by component **457**, which pads the most significant bits with 0s. The memory unit **455** has a different endian (big endian vs. little endian) ordering and is aligned to the unified format by a component **458**, which reverses the bit order and pads the remaining most significant bits with 0s. The unified data provided by the memory unit **453**, component **457**, and component **458** are merged using the OR gate **452**.

Returning to the memory repair scenario **400** of FIG. 4A, ECC repairs or incremental repairs are performed as desired. In one example repair scenario, the BIST unit **202** tests an entire memory set by writing/reading data to/from the memory units **404A-404C**. The data written to the memory units **404A-404C** is compared by reading an expected data to determine if the memory operations pass or fail. In response to a failed memory operation, a repair is performed and the BIST unit **202** tests the memory units **404A-404C** again. As needed, the test and repair process is repeated.

In some examples, ECC repairs have higher priority relative to incremental repairs (e.g., ECC repairs are performed until there are no more errors can be corrected by ECC, then incremental repairs are performed until there are

no more redundant columns available). In other examples, ECC repairs have lower priority relative to incremental repairs (e.g., incremental repairs are performed until there are no more redundant columns available for incremental repairs, then ECC repairs are performed until there are no more errors corrected by ECC). In other examples, the priority of ECC repairs relative to incremental repairs is selectable by a user.

In the memory repair scenario **500** of FIG. 5, various components are represented including the BIST unit **202**, the memory datapath switch **302**, the memory units **404A-404C**, the align and merge circuit **410**, the OR gate **412**, the repair analysis circuit **414**, and the fuse reconfiguration circuit **416**. The memory repair scenario **500** also includes shadow fuse registers **422A-422C**, OR gates **418A-418C** and **430**, and multiplexers **420A-420C** and **424**. The memory repair scenario **500** also includes a mode selection unit **502** and error mask components **504A** and **504B**. During the system power-up or initialization sequence before any functional or test operations on the memory units **404A-404C**, the shadow fuse registers **422A-422C** are reset/cleared and the memory repair data (possibly from prior test sessions) stored in FuseROM or a similar non-volatile memory is loaded into the corresponding memory repair registers **408A-408C** through the input **425A** and the multiplexer **424**. In parallel, the corresponding shadow fuse registers **422A-422C** are also initialized with the same memory repair data through the input **425B** and the multiplexers **420A-420C**. Thus, at the end of system initialization, the shadow fuse registers **422A-422C** have identical data as the corresponding memory repair registers **408A-408C**. In the example of FIG. 5, a test controller circuit (e.g., the test controller **114** of FIG. 1) controls the multiplexers **424**, **420A-C** and enables incremental repair components **410**, **414**, **416**, **422A-422C**. In different examples, the components represented for the memory repair scenario **500** are part of an IC, SoC, or multi-die module.

In the memory repair scenario **500**, the BIST unit **202** performs various operations to test memory units **404A-404C** before and after a repair is complete. In the memory repair scenario **500**, the memory units **404A** and **404C** support ECC repairs and incremental repairs. Meanwhile, the memory unit **404B** supports incremental repairs only while relying on memory unit **404C** for ECC repair. Again, the memory unit **404A** includes: 1) additional storage **406A** to store a signature for ECC repairs; and 2) a set of redundant row/column elements **408A** to support incremental repairs. Also, the memory unit **404B** includes a set of redundant row/column elements **408B** to support incremental repairs. Also, the memory unit **404C** includes: 1) additional storage **406B** to store a signature for ECC repairs; and 2) a set of redundant row/column elements **408A** to support incremental repairs. Each of the sets of ECC signature elements **406A** and **406B** may have the same number or a different number of bits. Also, each of the sets of redundant row/columns **408A-408C** may have the same number or a different number of redundant elements. Thus, each of the memory units **404A-404C** includes its own repair architecture in the memory repair scenario **500**.

To perform memory repairs in the memory repair scenario **500**, the BIST unit **202** tests the memory units **404A-404C** to determine if memory repair is needed. In response to the test from BIST unit **202**, the local compare circuits **405A-405C** compute the error from the respective memory units **404A-404C**. The local compare circuits **405A-405C** are instances of the local compare circuit **255** of FIG. 2B to compute the error from the memory units **404A-404C**. The

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determination of whether there is an available row/column in the memory repair scenario **500** is based on the availability of redundant rows/columns as well as the operations of the mode select unit **502** and of the error mask units **504A** and **504B**. For example, if the mode select unit **502** is configured to bypass ECC repairs, the error mask units **504A** and **504B** are disabled and not provided to the BIST unit **202**. On the other hand, if the mode select unit **502** is configured to allow ECC repairs, the error mask units **504A** and **504B** operate and mask ECC correctable errors before providing the result to the BIST unit **202**. Regardless of whether ECC repairs are enabled or disabled in the memory repair scenario, incremental repairs may be performed until redundant columns are unavailable.

Based on the available redundant row/column information provided and the ECC error mask outputs, the BIST unit **202** selects a redundant row/column or ECC error mask (e.g., error masks **504A** and **504B**) for repair according to a predetermined repair priority scheme (e.g., ECC repairs are assigned higher or lower priority relative to incremental repairs when ECC repairs are enabled by the mode select unit **502**). The selected repair is added to all other previous repairs by the align and merge circuit **410**. The repair information from the align and merge circuit **410** is provided to a repair analysis circuit **414** via an OR gate **412**. The output of the repair analysis circuit **414** is provided back to the OR gate **412**.

The output of the repair analysis circuit **414** is also provided to a fuse reconfiguration circuit **416**, which performs the inverse operation of the align and merge circuit **410** to reconfigure the repair analysis output in the unified format (converted by the align and merge circuit **410**) back to the target memory repair architecture. The fuse reconfiguration circuit **416** then writes cumulative writes repair information (a repair signature for each of the memory units **404A-404C**) to shadow fuse registers **422A-422C**. The OR gates **418A-418C** merge the previously stored repair signature from the shadow fuse registers **422A-422C** (either from the power-up initialization or prior test sessions) with the new repair signature from the fuse reconfiguration unit **416** and the multiplexers **420A-420C** configure the shadow fuse registers **422A-422C** to store the new merged repair signature. As shown, the outputs from each of the shadow fuse registers **422A-422C** is fed back to a respective OR gate **418A-418C** and multiplexer **420A-420C**.

After the BIST unit **202** completes testing on all the memory units **404A-404C**, the newly identified memory repair signature from the shadow fuse registers **422A-422C** is stored into the memory repair registers **408A-408C** by shifting out through the other input of the multiplexer **424**. The other input to the multiplexers **420A-420C** are configured to form a shift register by passing the repair information from adjacent shadow fuse registers for each of the memory units **404A-404C**. Again, the output from the shadow fuse register **422A** (corresponding to the memory unit **404A**) is fed into a multiplexer **424**, where the output of the multiplexer **424** is provided to the memory unit **404C**. While the data from shadow fuse register **422A** is shifted into memory repair register **408C**, the data stored in the shadow fuse registers **420C** and **420B** would have also been shifted into **420B** and **420A**, respectively. This process continues till the repair registers **408A**, **408B** and **408C** are initialized with the data from the shadow fuse registers **422A**, **422B** and **422C** respectively. The OR-gate **430** ensures that the shadow fuse registers **422A-422C** re-circulates its data back during this process. This enables full incremental repair where previous memory repair data stored in **408A-408C** which was iden-

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tical to those stored in the shadow registers **422A-422C** (either from initial load from FuseROM or from previous BIST executions), is cumulated with the fails from the new BIST test session and repaired back into the respective memory units. At any point in the process (e.g., at local compare or ECC error mask, at align and merge, at repair analysis, at fuse reconfiguration, at shadow fuse accumulation, etc.), if a non-repairable error or a failure is identified, the BIST unit **202** asserts an error indicating a non-repairable failure.

In one example repair scenario, the BIST unit **202** tests each of the memory unit **404A-404C** by performing a write/read operation. The data written to the memory units **404A-404C** is compared by reading an expected data to determine if each memory operation passes or fails. In response to a failed memory operation, a repair is performed and the BIST unit **202** tests the memory units **404A-404C** again. As needed, the test and repair process is repeated.

When ECC-aware testing is enabled, the error mask units **504A** and **504B** compare data and mask ECC correctable errors. Also, in some examples, multiple memory units (e.g., the memory units **404B** and **404C**) are tested as one entity by the BIST unit **202**. When incremental repairs are performed, data is written to the memory unit **404A**. The expected read data is compared, aligned to a uniform format, analyzed for repair, and cumulated with prior fails. New repair data is reconfigured back to the format for the memory unit **404A** and cumulated with prior repairs in the shadow fuse register **422A** for the memory unit **404A**. Also, initialization of repair and shadow (broadcast in parallel) from fuse components **425A** and **425B** (e.g., FuseROM or other non-volatile memory) is performed, and repair contents are transferred from the shadow fuse register **422A** back to the memory unit **404A** in the same order. The same process is repeated for the memory unit **404B** and **404C** using their respective shadow fuse registers **422B** and **422C**.

In the memory repair scenario **500**, ECC repairs are enabled or disabled as desired by the mode selection unit **502**. When ECC repairs are enabled, ECC repairs or incremental repairs are performed according to a predetermined priority scheme. In some examples, ECC repairs have higher priority relative to incremental repairs (e.g., ECC repairs are performed until there are no ECC correctable errors, then incremental repairs are performed until there are no more redundant row/columns available). In other examples, ECC repairs have lower priority relative to incremental repairs (e.g., incremental repairs are performed until there are no more redundant row/columns available for incremental repairs, then ECC repairs are performed until there are no ECC correctable errors). In other examples, the priority of ECC repairs relative to incremental repairs is adjustable based on user input or predetermined rules.

In this description, the term “couple” or “couples” means either an indirect or direct wired or wireless connection. Thus, if a first device couples to a second device, that connection may be through a direct connection or through an indirect connection via other devices and connections. The recitation “based on” means “based at least in part on.” Therefore, if X is based on Y, X may be a function of Y and any number of other factors.

Modifications are possible in the described embodiments, and other embodiments are possible, within the scope of the claims.

What is claimed is:

1. A system, comprising:
a processor;

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a memory coupled to the processor, wherein the memory includes a plurality of different memory units, each of the different memory units having its own repair architecture;

a memory repair circuit coupled to the memory, wherein the memory repair circuit comprises:

- a first repair circuit associated with a first repair type, wherein the first repair circuit is an error-coding correction (ECC) circuit, and wherein the memory repair circuit includes a test circuit configured to:
 - provide a local pass/fail determination for each of the different memory units;
 - provide ECC-aware regionalization of a dataword; and
 - provide ECC-aware error masking;
- a second repair circuit associated with a second repair type, wherein the second repair type is different than the first repair type; and
- a test controller configured to:
 - select between the first repair circuit and the second repair circuit to perform an in-field self-repair of the memory.

2. The system of claim 1, wherein the test controller selects the first repair circuit to perform an in-field self-repair on one of the different memory units in response to the test controller determining that a repair compatible with the first repair circuit is available.

3. The system of claim 1, wherein the test controller selects the second repair circuit to perform in-field self-repair on one of the different memory units in response to the test controller determining that a repair compatible with the first repair circuit is not available.

4. The system of claim 1, wherein the memory repair circuit comprises:

- a repair analyzer circuit configured to reconfigure itself based on respective repair architectures for each of the different memory units; and
- a shadow fuse register for each of the different memory units, wherein each shadow fuse register is configured to be initialized upon every electronic fuse autoloading along with a respective memory unit.

5. The system of claim 4, wherein the memory repair circuit is configured to provide a cumulative repair code for different memory test sessions, and to assert an error in response to identifying a non-repairable error based on the cumulative repair code.

6. The system of claim 4, wherein the memory repair circuit is configured to selectively reload contents of a shadow fuse register into a respective one of the different memory units to perform in-field self-repair operations.

7. A device, comprising:

- a memory;
- a memory repair circuit coupled to the memory, wherein the memory repair circuit comprises:
 - a test circuit;
 - an error mask circuit configured to determine a number of bit errors;
 - an incremental repair circuit; and
 - a test controller coupled to the test circuit, the error mask circuit, and the incremental repair circuit, wherein the test controller is configured to select between the error mask circuit and the incremental repair circuit to perform an in-field self-repair of the memory.

8. The device of claim 7, wherein the memory includes a plurality of different memory units, each of the different

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memory units having its own repair architecture, and wherein the test circuit is configured to:

- provide a local pass/fail determination for each of the different memory units;
- provide error-correcting code (ECC)-aware regionalization of a dataword; and
- provide ECC-aware error masking using the error mask circuit.

9. The device of claim 8, wherein the memory repair circuit comprises:

- a repair analyzer circuit configured to reconfigure itself based on respective repair architectures for each of the different memory units; and
- a shadow fuse register for each of the different memory units, wherein each shadow fuse register is configured to be initialized upon every electronic fuse autoloading along with a respective memory unit.

10. The device of claim 9, wherein the memory repair circuit is configured to provide a cumulative repair code for different memory test sessions, and to assert an error in response to identifying a non-repairable error based on the cumulative repair code.

11. The device of claim 9, wherein the memory repair circuit is configured to selectively reload contents of a shadow fuse register into a respective one of the different memory units to perform in-field self-repair operations.

12. The device of claim 7, wherein the test controller is configured to prioritize repairs by the error mask circuit over repairs by the incremental repair circuit.

13. The device of claim 7, wherein the test controller is configured to prioritize repairs by the incremental repair circuit over repairs by the error mask circuit.

14. A system-on-a-chip (SoC), comprising:

- a memory with a plurality of different memory units, each of the different memory units having its own repair architecture;
- a memory repair circuit coupled to the memory, wherein the memory repair circuit comprises:
 - a test circuit configured to:
 - provide a local pass/fail determination for each of the different memory units within the memory;
 - provide error-correcting code (ECC)-aware regionalization of a dataword; and
 - provide ECC-aware error masking;
 - a repair circuit configured to repair in-field self-repair of the memory;
 - a test controller coupled to the test circuit and the repair circuit, wherein the test controller is configured to selectively enable and disable the repair circuit.

15. The SoC of claim 14, wherein the repair circuit is a first repair circuit, wherein the memory repair circuit comprises a second repair circuit, and wherein the test controller is configured to select between the first repair circuit and the second repair circuit to perform an in-field self-repair of the memory.

16. The SoC of claim 14, wherein the memory repair circuit comprises:

- a repair analyzer circuit configured to reconfigure itself based on respective repair architectures for each of the different memory units; and
- a shadow fuse register for each of the different memory units, wherein each shadow fuse register is configured to be initialized upon every electronic fuse autoloading along with a respective memory unit.

17. The SoC of claim 16, wherein the memory repair circuit is configured to provide a cumulative repair code for

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different memory test sessions, and to assert an error in response to identifying a non-repairable error based on the cumulative repair code.

18. The SoC of claim **16**, wherein the memory repair circuit is configured to selectively reload contents of a shadow fuse register into a respective one of the different memory units to perform in-field self-repair operations.

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